Phys525:
Quantum Condensed Matter Physics: Quantum Criticality
Basics, Dynamics and Topological criticality

episode One: Introduction and Why Quantum criticality?

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- Why Quantum criticality? your opinions...

Interacting quantum many-body systems:
"emergent phenomena"

More Is Different

Broken symmetry and the nature of the hierarchical structure of science.

P. W. Anderson

The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted

planation of phenomena in terms of known fundamental laws. As always, distinctions of this kind are not unambiguous, but they are clear in most cases. Solid state physics, plasma physics, and perhaps

less relevance they seem to have to the very real problems of the rest of science, much less to those of society.

The constructionist hypothesis breaks down when confronted with the twin difficulties of scale and complexity. The behavior of large and complex aggregates of elementary particles, it turns out, is not to be understood in terms of a simple extrapolation of the properties of a few particles. Instead, at each level of complexity entirely new properties appear, and the understanding of the new behaviors requires research which I think is as fundamental in its nature as any other. That is, it seems to me that one may array the sciences roughly linearly in a hierarchy, according to the idea: The elementary entities of science X obey the laws of science Y.

Large scale quantum phenomena can't be understood as a simple extrapolation of microscopic individual particles. Strong interactions lead more exotic phenomena.

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SCIENCE

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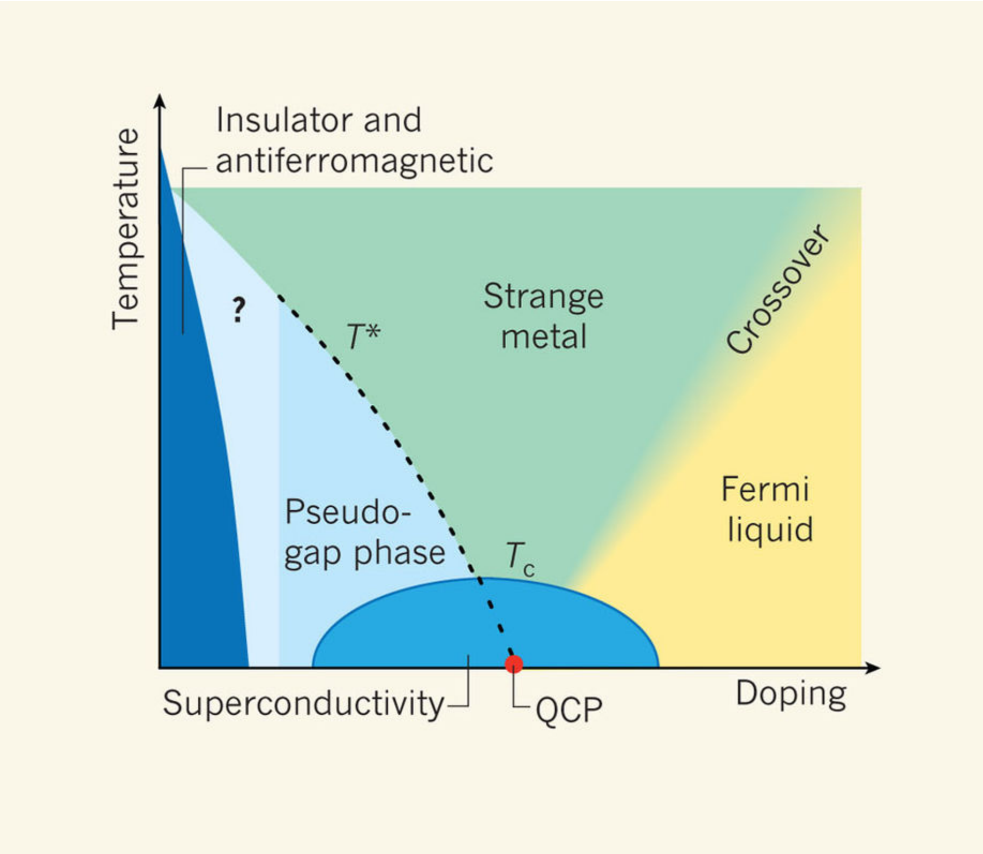
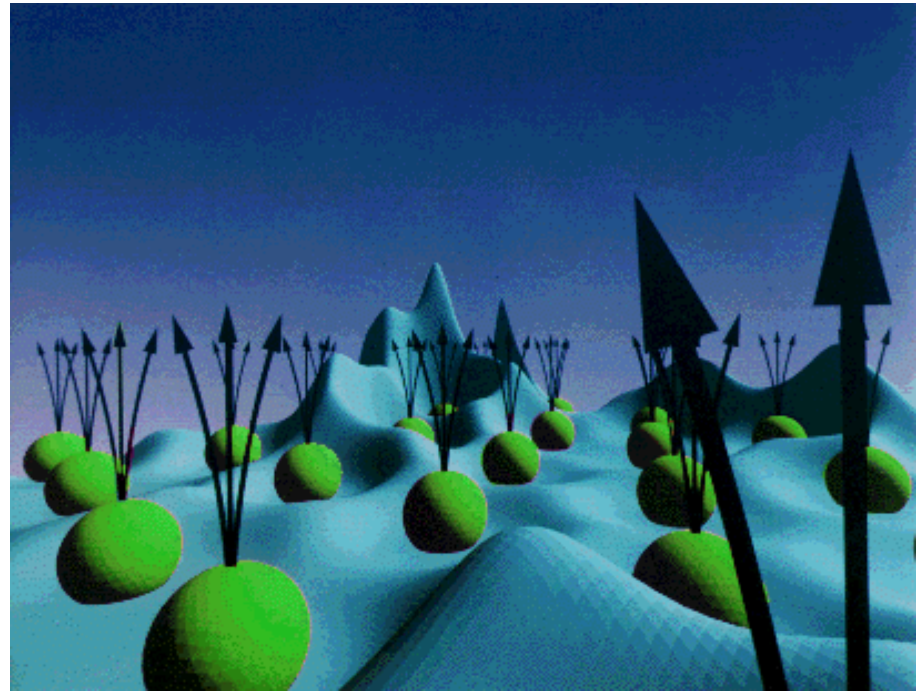
Emergent Quantum Phenomena: More is different





Superconductor (HTcS)
1) electrons can condense and super-flow!
2) strongly interacting electron can super-conduct at high T.

Fractional Quantum Hall (FQH)
Laughlin state with 1/3 electron per flux in B-field
Quasi- particles carrying 1/3 of electron charges.

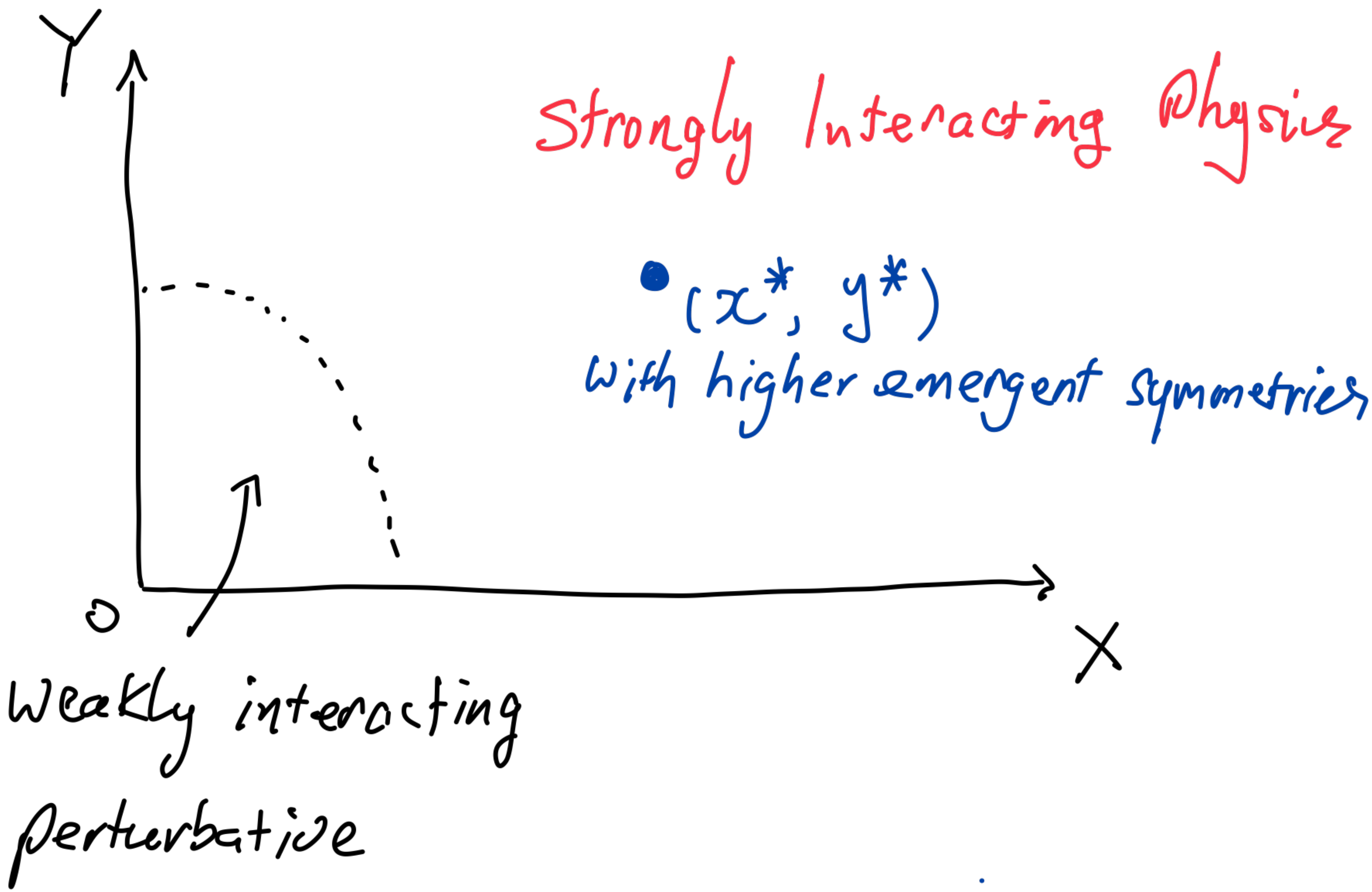
“emergent phenomena” and
why they are surprising?
More is different!

A) Quantum matter can break the symmetries of the microscopic interactions (Superconductor/superfluid, ferromagnetic-anti-ferromagnetic etc)

B) Strong interactions +high “degeneracy” due to either quantum or classical configurations; leading to fractionalization/non-local ”topological order” (i.e.FQHs, spin liquids etc); an exciting frontier.

C) Strong interactions but fine tuned to certain points where scale (and/or conformal) symmetries emerge as a large scale quantum phenomena.

Equally Important: An Alternative Path to Strongly Interacting physics



Physics 525 Advanced Condensed Matter Physics:
Tues, Thur 12:30-2:00pm

Part I: Basics on quantum criticality

0) Basic ideas of Phase transitions and critical phenomena: Fluctuations and interactions

1) Scale symmetry and Wilson-Fisher strong coupling fixed points

2) Concept of Quantum phase transitions and Quantum critical points (regimes)

3) Standard approach to quantum criticality via quantum field theories

4) Celebrated examples of Quantum critical points (QCPs)

Part II: Dynamics near Quantum critical points (QCPs)

1) *Kimble-Zurek mechanism near QCPs and applications to quenched many-body dynamics;*

2) *Universal Transport phenomena near strongly coupling QCPs;*

3) *Planckian transport in a few strongly interacting condensed matter systems;*

4) *Hydrodynamics near QCPs: nearly perfect quantum liquids;*

5) *Quantum dynamics near QCPs with dynamic critical exponent z=2: SO(2,1) conformal symmetry a) Weak and strong coupling fixed points; b) The issue of bulk and shear viscosity; c) Quantum Boltzmann breathers.*

Part III: More recent applications: QCPs in Quantum topological Matter

1) *Beyond-Landau-paradigm quantum phase transitions driven by global topologies QCPs in TSF and TSCs*

2) *Bulk signatures of QCPs and what happens to surface states*

3) *Strong coupling topological QCPs*

4) *Surface states as QCPs*

5) *Emergent SUSY in topological matter and topological surfaces*

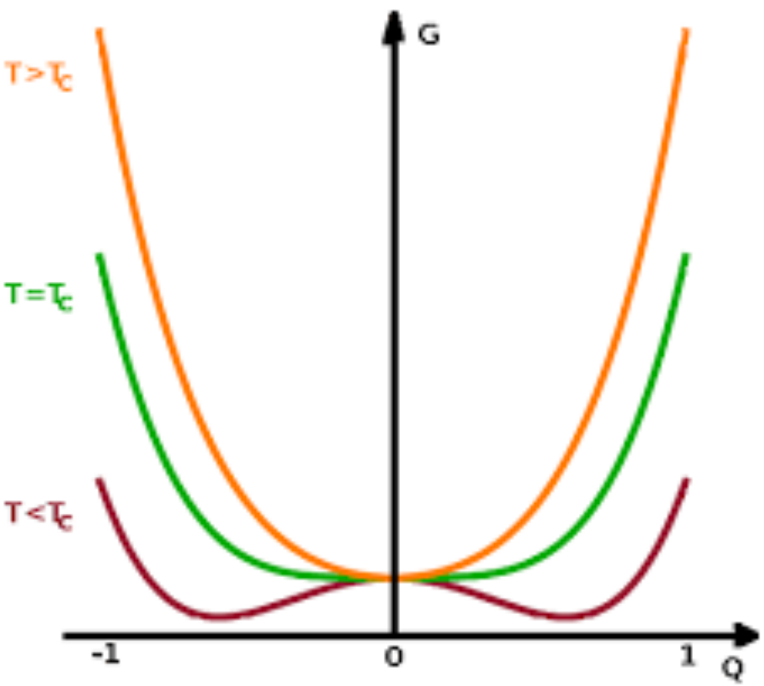
General References:

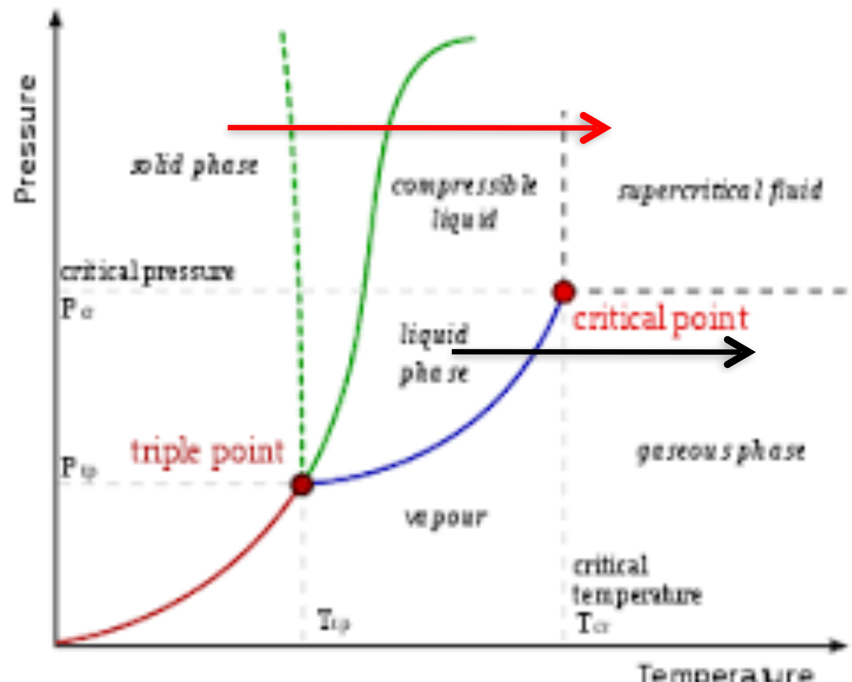
1) Quantum Phase Transitions, Subir Sachdev (Cambridge University Press, 2nd ed., 2011)
2) An introduction to Quantum field theory, Michael Peskin and Daniel Schroeder (CRC press, Taylor and Francis, 1995)

more special references will be provided after Part I.

Ideally,Phys516, Phys526 set the starting points for our discussions.

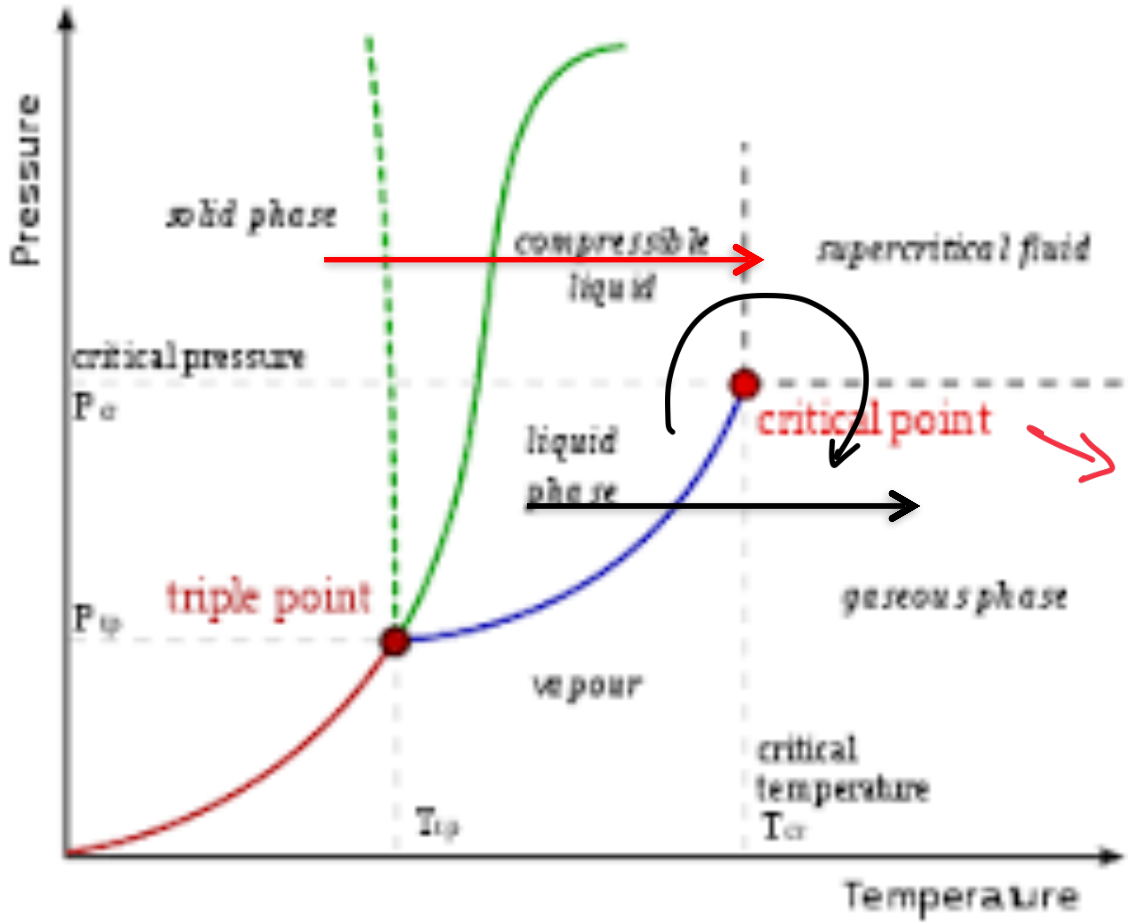
Landau paradigm for order-disorder Phase Transitions





There have to be phase transitions if ordering occurs.

Landau paradigm for order-disorder Phase Transitions



→ Related to Topological Quantum phase transition

There have to be phase transitions if ordering occurs.